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Translaryngeal tracheostomy in acute respiratory distress syndrome patients

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Abstract *Objective:* To prevent gas exchange deterioration during translaryngeal tracheostomy (TLT) in patients with acute respiratory distress syndrome (ARDS) ventilation is maintained through a small diameter endotracheal tube (ETT; 4.0 mm i.d.) advanced beyond the tracheostoma. We report on the feasibility of uninterrupted ventilation delivered through a high-resistance ETT in ARDS patients, and relevant ventilatory adjustments and monitoring. *Design and setting:* Prospective, observational clinical study in an eight-bed intensive care unit of a university hospital. *Patients:* Eight consecutive ARDS patients scheduled for tracheostomy. *Interventions:* During TLT volume control ventilation was maintained through the 4.0-mm i.d. ETT. Tidal volume, respiratory rate, and inspiratory to expiratory ratio were kept constant. Fractional inspiratory oxygen was 1. Positive end expiratory pressure (PEEP) set on the ventilator ($PEEP_{vent}$) was reduced to maintain total PEEP ($PEEP_{tot}$) at baseline level according to the measured intrinsic PEEP (auto-PEEP). *Measurements and main results:* Data were collected before tracheostomy and while on mechanical ventilation with the 4.0-mm i.d. ETT. Neither $PaCO_2$ nor PaO_2 changed significantly (54.5±10.0 vs. 56.4±7.0 and 137±69 vs. 140±59 mmHg, respectively). Auto-PEEP increased from 0.6±1.1 to 9.8±6.5 cmH_2O during ventilation with the 4.0-mm i.d. ETT. By decreasing $PEEP_{vent}$ we obtained a stable $PEEP_{tot}$ (11.4±4.3 vs. 11.8±4.3 cmH_2O), and end-inspiratory occlusion pressure (26.7±7.4 vs. 28.0±6.6 cmH_2O). Peak inspiratory pressure rose from 33.8±8.1 to 77.8±12.7 cmH_2O. *Conclusions:* The high-resistance ETT allows ventilatory assistance during the whole TLT procedure. Assessment of stability in plateau pressure and $PEEP_{tot}$ by end-inspiratory and end-expiratory occlusions prevent hyperinflation and possibly barotrauma.

Keywords Tracheostomy · Percutaneous, translaryngeal · Acute respiratory distress syndrome · Oxygenation · Mechanical ventilation · Airway resistance · Intrinsic positive end-expiratory pressure

Introduction

Fantoni and colleagues [1, 2] recently proposed a percutaneous translaryngeal tracheostomy (TLT) technique in which the tracheal cannula, provided with a metal cone tip, is passed from the mouth through the larynx in the trachea and then pulled out to the surface in a single step. As with all the tracheostomy techniques, gas exchange often deteriorates during the procedure [3, 4, 5, 6]. In patients with acute respiratory distress syndrome (ARDS) impairments in oxygenation may be critical.

Table 1 Patients' characteristics and clinical data before tracheostomy (*ESA* acute subarachnoid hemorrage, *VAP* ventilator-associated pneumonia, *BIPAP* biphasic intermittent positive airway pressure, *PCV* pressure-controlled ventilation, *SIMV-PS* synchronized intermittent mandatory ventilation with pressure support ventilation, *LIS* lung injury score)

Patient no.	Sex	Age (years)	Diagnosis	Mode	PEEP (cmH_2O)	FIO_2	MV (l/min)	PaO_2 (mmHg)	$PaCO_2$ (mmHg)	LIS
1	M	77	Bacterial pneumonia	VCV	10	1	9.5	81	41	2.5
2	M	71	ESA, VAP	SIMV-PS	12	1	11.3	132	57	2.5
3	F	63	Bacterial pneumonia	SIMV-PS	5	0.60	6.3	108	60	3.0
4	M	47	Bacterial pneumonia, sepsis	BIPAP	8	0.80	12.0	101	65	3.5
5	M	74	Polytrauma, VAP	BIPAP	12	0.70	8.1	125	52	2.5
6	M	64	*Chlamydia pneumonia*	SIMV-PS	10	0.60	11.5	110	54	3.25
7	F	70	Abdominal sepsis	PCV	12	1	9.1	74	47	2.25
8	M	63	Bacterial pneumonia	SIMV-PS	12	0.60	7.2	96	76	3.25
Mean	–	66.4	–	–	10.1	0.79	9.4	103	56	2.8
±SD	–	10.0		–	2.7	0.19	2.1	20	11	0.5

As originally described, TLT requires two apneic intervals: one during the replacement of the endotracheal tube (ETT) by a rigid tracheoscope and a longer one during placement of the tracheal cannula. To overcome the second longer apneic interval, Fantoni et al. [1, 2] proposed the use of a 40-cm long 4.0-mm i.d. ETT to maintain ventilation during the procedure. Recent studies on TLT conducted on a group including patients with ARDS [7, 8, 9] do not provide details on ventilatory support during the procedure. We have encountered a marked increase in airway resistance caused by the 4.0-mm i.d. ETT, and the build-up of intrinsic positive end-expiratory pressure (auto-PEEP), hyperinflation, and possibly barotrauma. On the other hand, positive airway pressure is necessary in patients with ARDS to preserve oxygenation.

The aim of the present study was to evaluate the feasibility of uninterrupted, conventional mechanical ventilation delivered through a high-resistance ETT in ARDS patients, and to describe the ventilatory monitoring and adjustments that we apply to this end.

Materials and methods

Eight consecutive intubated patients underwent elective TLT. The patients had a diagnosis of ARDS [10, 11] and had been scheduled for tracheostomy because of an expected need for prolonged ventilatory support and tracheal intubation [12]. Written informed consent was obtained from the patient's next of kin. Exclusion criteria were intracranial hypertension, goiter, facial or cervical spine injuries. Obesity, tracheal deviation and squat neck or bleeding disorders were not considered as absolute contraindications. Sedation and muscle paralysis were achieved by continuous infusion of fentanyl, propofol, and pancuronium bromide in boluses. Patients characteristics before tracheostomy are presented in Table 1.

Monitoring and measurements

All patients had invasive monitoring of central venous pressure (CVP) and arterial blood pressure (BP) already in place. Arterial samples were collected when needed for blood gas analysis (ABL 330, Radiometer, Copenhagen, Denmark). Heart rate (HR), pulse oximetry, and end-tidal CO_2 (4700 OxiCap Monitor, Ohmeda, Louisville, Colo., USA) were continuously monitored throughout the procedure.

Airway pressure and flow at the proximal end of the ETT were obtained by a pneumotachograph (Bicore Monitoring System, Irvine, Calif., USA) connected to a computer for storage and data analysis. Tidal volume (V_T) was obtained by digital integration of the airflow tracing. Auto-PEEP and plateau pressure (P_{plat}) were measured by end-expiratory and end-inspiratory occlusions, respectively. Occlusions lasted 3–4 s to allow for equilibration. Total inspiratory resistance, including artificial airways (Raw_{rs}) was calculated from airflow and airway pressure [13]. Airway pressure and flow were continuously displayed and recorded throughout the procedure.

Data are presented (a) at baseline (15 min after induction of general anesthesia), (b) while on mechanical ventilation through the 4.0-mm i.d. ETT following extraction and rotation of the cannula (see below), and (c) 15 min after resuming mechanical ventilation at baseline ventilatory settings through the tracheal cannula.

Translaryngeal tracheostomy

TLT was performed by at least one experienced operator, with the assistance of a second ICU physician. A third one took care of anesthesia, ventilatory monitoring and adjustments. A commercially available kit (Mallinckrodt Medica, Mirandola, Italy) was used. A 7.5-mm i.d. tracheal cannula was used for women and an 8.5-mm i.d. for men.

The patient's translaryngeal tube was replaced by the rigid cuffed tracheoscope supplied with the kit. The tracheoscope was used to identify the site of tracheal puncture under vision with a rigid fiberscope (Flexilux 250 endo, Scholly Fiberoptic, Denzlingen, Germany). The trachea was punctured between the second and third rings using a curved needle directed cranially. A guidewire inserted through the needle was advanced inside the tracheoscope until the tube connector was reached. The tracheoscope was replaced with the 40-cm long 4.0-mm i.d. ETT, positioned in the lower third of the trachea. After adjustment of the ventilator settings (see below) the tracheal cannula was introduced from the mouth and tractioned using the guidewire from the tracheal lumen out of the skin. The cannula was extracted and rotated to its final position. The 4.0-mm i.d. ETT was removed, and mechanical ventilation was resumed with baseline parameters through the newly placed tracheal cannula. Duration of the procedure was timed from the replacement of the rigid cuffed tracheoscope with the 4.0-mm i.d. ETT, to the final placement of the cannula. Chest radiography was performed to exclude complications.

Mechanical ventilation

When not already the case, before the procedure all patients were connected to a Servo ventilator 900 C (Siemens-Elema, Solna, Sweden). After induction of general anesthesia and muscle paralysis, patients were ventilated in volume control mode (VCV) with fractional inspiratory oxygen (FIO_2) of 1. After reintubation with the 4.0-mm i.d. ETT, baseline V_T, respiratory rate (RR), and inspiratory to expiratory ratio (I:E=1:2) were not modified. The internal working pressure of the ventilator was raised to 120 cmH_2O, to allow for an adequate peak inspiratory pressure (PIP). Auto-PEEP was measured, and PEEP at the ventilator ($PEEP_{vent}$) was decreased in steps of 2 cmH_2O until total PEEP ($PEEP_{tot}$, i.e., the sum of auto-PEEP and $PEEP_{vent}$) returned to baseline. Once a stable $PEEP_{vent}$ was reached (usually in less than four steps within 5 min), P_{plat} was measured to verify substantial identity to baseline. From then on PIP monitored any abrupt change in auto-PEEP with ongoing hyperinflation or sudden increase in resistance. The PIP pop-off alarm was individually set 5 cmH_2O above the observed value.

Statistical analysis

All data are expressed as mean ±standard deviation. Two-way analysis of variance for repeated measurements was used for all variables to verify differences among steps. When differences were significant ($p<0.05$) on analysis of variance, Bonferroni's correction was used.

Results

The average intubation time before tracheostomy was 9.6±1.8 days. Average duration of the TLT procedure was 7.5±7.4 min (median 8, range 1.3–15.0). No major adverse events or short-term complications were observed.

Hemodynamics

During the procedure no significant changes were detected between baseline and 4.0-mm i.d. ETT ventilation in HR (113±31 vs. 112±25 bpm, respectively) nor in mean BP (76±9 vs. 88±7 mmHg). The same was observed for CVP (12.6±2.7 vs. 13.8±3.2 mmHg, respectively). At the end of the procedure hemodynamics were not significantly different from baseline (data not shown).

Table 2 Gas exchange at different steps of tracheostomy

	Before TLT	4.0-mm i.d. ETT	After TLT
PaO_2 (mmHg)	137±69	140±59	112±57
$PaCO_2$ (mmHg)	54±10	56±7	57±11
pH	7.39±0.07	7.38±0.05	7.39±0.07
HCO_3^- (mmol/l)	35.0±4.3	31.5±3.2	34.0±4.0
Base excess	6.0±2.0	4.5±1.5	5.5±2.2

Gas exchange and ventilatory pattern

Blood gases are summarized in Table 2. No significant changes in PaO_2 were detected in any patient. Oxygen saturation was stable except for transient drops during the positioning of the tracheoscope and/or the 4.0-mm i.d. ETT. A stable ventilation was obtained with constant $PaCO_2$ and pH throughout the procedure. Ventilatory data at the different steps of the procedure are shown in Table 3. A marked increase in PIP and in Raw_{rs} was observed during the 4.0-mm i.d. ETT ventilation. As shown in Fig. 1 in a representative patient, ventilation with 4.0-mm i.d. ETT resulted in a marked increase in auto-PEEP. Auto-PEEP increased from 0.6±1.1 cmH_2O at baseline to 9.8±6.5 cmH_2O and was counteracted by reducing $PEEP_{vent}$ from 10.8±4.3 to 2.0±5.4 ($p<0.01$). As shown in Fig. 2, we achieved a stable $PEEP_{tot}$. At the end of tracheostomy $PEEP_{vent}$ was returned to baseline. No significant differences were detected in P_{plat} at any stage (Table 3, Fig. 1). Although not statistically significant, V_T was slightly lower during ventilation through

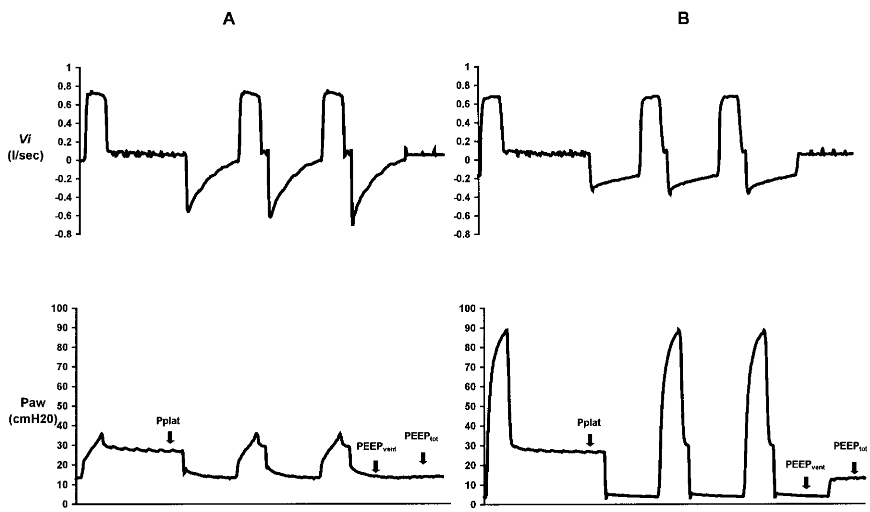

Fig. 1A, B Airflow and airway pressure tracings in patient 5. **A** Baseline ventilation with a 8.0 mm i.d. ETT. **B** Ventilation during tracheostomy through the 4.0-mm i.d. ETT. *Arrows* Airway pressure at manual end-inspiratory occlusion (P_{plat}) and at end-expiratory occlusion (*auto-PEEP*). **B** Note the decrease in $PEEP_{vent}$; P_{plat} does not differ between the two panels. See text for detailed explanation

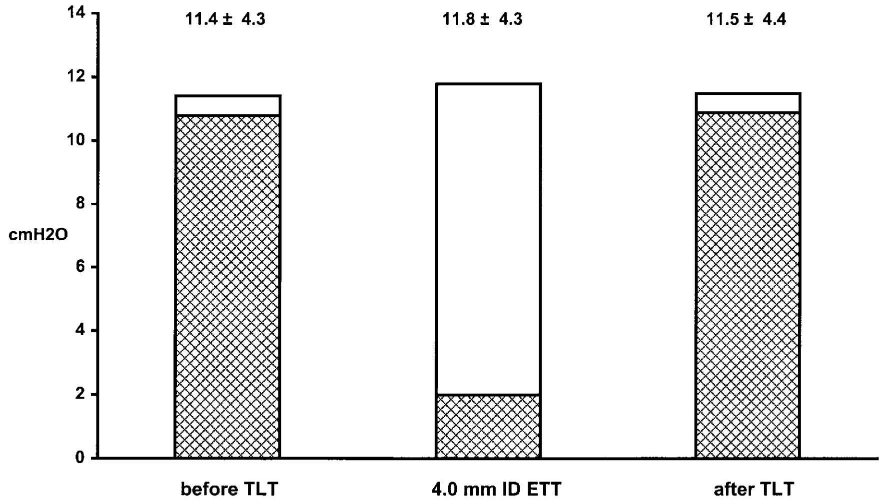

Fig. 2 Partitioning of auto-PEEP and $PEEP_{vent}$ at stages of tracheostomy. *Solid white bars* Average values of auto-PEEP; *dashed bars* $PEEP_{vent}$. $PEEP_{tot}$ (i.e., the sum of auto-PEEP and $PEEP_{vent}$) is indicated as mean±SD at each stage

Table 3 Ventilatory variables at different steps of tracheostomy (*PIP* peak inspiratory pressure, P_{plat} end inspiratory occlusion pressure, $PEEP_{vent}$ positive end-expiratory pressure at the ventilator, *auto-PEEP* intrinsic positive end-expiratory pressure at end-expiratory pause, Raw_{rs} total inspiratory resistance, V_I mean inspiratory flow, *RR* respiratory rate, V_T tidal volume)

	Before TLT	4.0-mm i.d. ETT	After TLT
PIP (cmH_2O)	33.8±8.1	77.8±12.7*	32.7±7.8
$PEEP_{vent}$ (cmH_2O)	10.8±4.3	2.0±5.4	10.9±4.4
auto-PEEP (cmH_2O)	0.6±1.1	9.8±6.5	0.6±1.1
P_{plat} (cmH_2O)	26.7±7.4	28.0±6.6	25.9±7.3
Raw_{rs} (cmH_2O/l/s)	12.6±4.7	82.9±22.5*	12.3±4.0
V_I (l/s)	0.6±0.12	0.61±1.15	0.58±0.15
RR (bpm)	13.2±1.7	13.2±1.7	13.2±1.7
V_T (ml)	709±136	624±159*	705±145

*$p<0.01$ vs baseline

the 4.0-mm i.d. ETT. Baseline values were restored at the end of tracheostomy (Table 3).

Discussion

The addition of endoscopic guidance to percutaneous tracheostomy techniques has further increased the safety of these procedures. However, ventilation with the bronchoscope in place may result in hypoventilation, hypercapnia [4], and loss of airway pressures. In particular, TLT as reported so far, does not protect from deterioration in gas exchange. A recent study conducted in a group of head-injured patients reports increased $PaCO_2$ during TLT [14], likely the result of decreased alveolar ventilation. A comparative study between percutaneous dilatational tracheostomy (PDT), TLT, and surgical tracheostomy [15] reported a decreased oxygenation with all techniques. Another recent study comparing PDT and TLT performed on a group including ARDS patients suggested that $PaCO_2$ was higher than during TLT than during PDT, while the PaO_2/FIO_2 ratio was significantly lower in PDT than TLT [8]. The same authors reported a rise in $PaCO_2$ and an increased postoperative FIO_2, although desaturation episodes were transient only during TLT [7]. Jet ventilation through a flexible fiberoptic bronchoscope during PDT has been described as useful for maintaining oxygenation [16]. Nevertheless, there is no control of V_T nor of PEEP, and the authors rely on visual inspection of chest expansions to monitor ventilation. Fantoni and colleagues [1] reported that manual jet ventilation through the small bore ETT could provide adequate ventilatory support. We believe that this mode of ventilatory assistance as well as manual ventilation via the 4.0-mm i.d. ETT carries some risk of lung overdistension without ensuring stability in gas exchange.

In our study the ability to maintain mechanical ventilation throughout the procedure led to a stable oxygenation and alveolar ventilation. Baseline auto-PEEP was negligible in all patients. The auto-PEEP developed during mechanical ventilation with the 4.0-mm i.d. ETT was the result of the marked increase in resistance and could be counteracted by reducing $PEEP_{vent}$. The stable elastic recoil pressure measured during the end-inspiratory pause and a constant $PEEP_{tot}$ should reflect a reasonably constant alveolar pressure [17]. Our study shows that during TLT in patients with ARDS the discontinuation of mechanical ventilation is avoidable while maintaining minute volume and airway pressure. Maintenance of mechanical ventilatory support can make this technique safer in patients highly dependent on airway pressure for oxygenation. Ensuring adequate ventilation and a stable airway pressure eliminates time as a critical issue. Adequate respiratory monitoring is necessary to achieve the desired PEEP and P_{plat} levels through proper adjustments of the ventilator settings.

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